Towards a Principled Representation of Discourse Plans

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Abstract

We argue that discourse plans must capture the intended causal and decompositional relations between communicative actions. We present a planning algorithm, DPOCL, that builds plan structures that properly capture these relations, and show how these structures are used to solve the problems that plagued previous discourse planners, and allow a system to participate effectively and flexibly in an ongoing dialogue.

Introduction

The close connection between discourse and intention is by now nearly universally accepted: generating discourse is an intentional activity, the structure of discourse reflects the structure of the participants' intentions, and understanding discourse involves, at least in part, recognizing the intentions of the language producer. Researchers working both on generation and interpretation are wont to exhibit "discourse plans" that represent the intentions of language users. However, there has been much confusion about exactly what constitutes a discourse plan, and what kind of algorithms should process them. Most of the work in computational linguistics has built on plan representations and planning algorithms that are at least a decade old—representations and algorithms that suffer from being unprincipled and difficult to analyze. These difficulties have spilled over into the NL systems that rely on them. Yet within the past few years, the literature on AI planning has grown significantly, and the older representations and algorithms have been reanalyzed and replaced with cleaner representations and algorithms whose formal properties are amenable to careful analysis.

In this paper, we illustrate some of the problems that arise from using these old plan representations and planning algorithms. We then show how more recent planning algorithms, called partial-order causal link (POCL) planners (McAllister and Rosenblitt, 1991; Penberthy and Weld, 1991), can be used to generate discourse plans. The particular planning algorithm we use is DPOCL, an algorithm that introduces action decomposition into a POCL framework (Young, Pollack and Moore, 1994). We show that the discourse plans produced by the DPOCL algorithm properly capture both the intended causal and decompositional relations among the communicative actions, and thereby solve the problems of earlier systems and allow a language-processing system to participate effectively and flexibly in an ongoing dialogue.

Previous Approaches

Discourse is typically viewed as having a hierarchical structure and therefore many discourse planners are based on the original NOAH (Sacerdoti, 1977) model of hierarchical planning (Appelt, 1985; Cawsey, 1993; Hovy, 1991; Maybury, 1992; Moore and Paris, 1993). These systems rely on customized planning algorithms with procedural semantics for the purposes of solving specific text-planning problems. The informal construction of these systems and their application to particular problems have resulted in successful text generation for limited domains and text types, while obscuring the undesirable properties of the algorithms. However, careful analysis of these programs shows that there is nothing in their semantics to prevent them from generating incorrect plans, generating plans with redundant steps, or failing to find plans in situations where they exist. To the extent that these planners have been able to avoid these problems, they have done so by severely limiting the expressive power of action descriptions and/or requiring the designer of action descriptions to handcraft each description to fit correctly into the *ad hoc* semantics of the specific plan for which the action is intended.

Within the planning literature, it has been noted that there are two different ways in which component actions of a plan may be related: an action ACT1 may provide causal support for another action ACT2 (i.e., ACT1 establishes a precondition of ACT2) or an action ACT1 may be part of the decomposition of ACT2. Similar distinctions have been noted in the NL literature, e.g., Grosz and Sidner's (1986) distinction between satisfaction-precedence and dominance and Pollack's (1990) distinction between enablement and generation.

The main problem with most previous discourse planning systems is that they have not adequately represented both the causal and decompositional relations between actions in a discourse plan. That is, they do

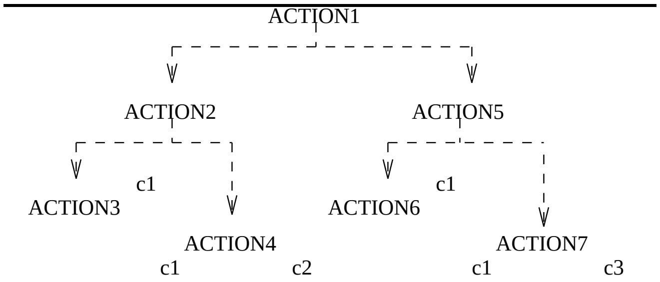

Figure 1: Schematic Discourse Plan Illustrating a Redundant Step

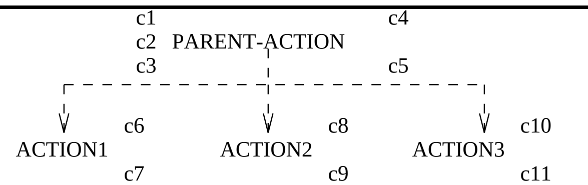

Figure 2: Schematic Discourse Plan Illustrating Parent/Subplan Effects

not reason about interactions between the effects of actions in the plan. More specifically, they do not reason about the establishment of preconditions, or the possibility that one step in the plan may accidentally undo or obviate the effect of another step. Moreover, in cases where they perform decomposition, they do not reason about the relationship between the effects of actions in a subplan and the effects of their parent action.

To illustrate two of these problems, consider the discourse plans shown schematically in Figures 1 and 2. In these figures, conditions, denoted by the c_i, appearing to the left of an action denote its preconditions and those appearing to the right of an action denote its effects. These plans have structure that is typical of those produced by most previous discourse planning systems (Cawsey, 1993; Hovy, 1991; Maybury, 1992; Moore and Paris, 1993). Figure 1 shows a plan where the effect $c1$ is established by two different actions occurring in different subtrees of the plan. This can occur because these planners do not consider the roles that previous actions' effects can play in satisfying the preconditions of subsequent discourse actions.[1] Thus, they cannot detect when an action added to establish one particular condition may serendipitously satisfy conditions of other steps in the plan. This failure may lead to the generation of texts that are (unintentionally) redundant or repetitive. An analogous, and possibly even more damaging, problem may result when these systems fail to notice that one action undoes the effect of another.

Figure 2 shows a plan where there is no explicit connection between the effects established by the parent action ($c4$ and $c5$) and those established by its subplan ($c6$ through $c11$). Previous approaches only represent the relationship between actions at different levels; they fail to capture the relationship between the effects of those actions. In Figure 2, the top-level goal is $c4 \wedge c5$. Suppose that $c6$ unifies with $c4$, and that $c8$, $c9$, and $c10$ together have a consequence that unifies with $c5$. In this case, $c7$ and $c11$ are side effects of choosing the decomposition of the PARENT-ACTION into ACTION1, ACTION2 and ACTION3. This fact, however, is not captured in the discourse plan of Figure 2. Hence a system relying on this plan could not distinguish intended effects from side effects, and so would be unable to determine that the failure of $c6$ warrants a different response than the failure of $c7$.

In short, these systems cannot, in general, determine how discourse actions are related to one another. Yet, as we will illustrate in the next section, understanding the intended relations between discourse actions is crucial to effective language generation.

The Significance of Discourse Plans

Consider the following sample discourse, a fragment of a political discussion between two participants, Sharon (S) and Harry (H).

> S: Wiggins will vote no on NAFTA. She's an ally of the unions. Her district is heavily industrial.

A plausible and typical analysis of this discourse is that Sharon's primary intention is to convince Harry that Wiggins will vote no on NAFTA. To achieve this goal, Sharon asserts the proposition in question (that Wiggins will vote no on NAFTA) and then supports it by claiming that Wiggins is an ally of the unions. To convince Harry of this later claim, Sharon supports it by claiming that Wiggins's district is heavily industrial.

Now consider these possible alternative responses by Harry to Sharon's statement:

> H1: I didn't think her district was industrial.

> H2: Lots of representatives from industrial districts vote against the union.

> H3: Well, she's certainly pro-union, but I didn't think her district was industrial.

> H4: Well, she's certainly pro-union, but lots of representatives from industrial districts support NAFTA.

[1] Appelt (1985) would solve this problem with critics, i.e., *ad hoc* procedures that check for certain types of plan interactions.

H5: I didn't think her district was industrial. And besides, lots of representatives from industrial districts support NAFTA.

How is Sharon to determine an appropriate response to these replies? As we have pointed out (Moore and Paris, 1993; Moore and Pollack, 1992), Sharon's response must take account of what Harry's reply reveals about which parts of Sharon's discourse plan were successful.

For example, in H1 Harry's failure to believe that Wiggins's district is industrial blocks the support that this claim would have provided to convince Harry of Wiggins's pro-union position. At this point Sharon has several options. She may try to convince Harry that Wiggins's district is, in fact, industrial. Alternatively, she may find some other support for the claim that Wiggins is pro-union or she may find some other means to support the anti-NAFTA claim altogether.

Implicit in Sharon's initial statement was her belief that Harry believed that, as a rule, a representative's position on labor is determined by the industrial make-up of her district. Together with Sharon's claim that Wiggins's district is industrial, this rule would have provided support to convince Harry of Wiggins's pro-union position. H2 indicates that the support for Sharon's claim that Wiggins is pro-union has failed. Sharon must either find an alternate discourse strategy for supporting it or must find some other means to support the anti-NAFTA claim. Notice the difference between H1 and H2. A plausible response to H1, but not H2, is to reestablish the proposition that Wiggins's district is industrial.

In H3 as in H1, Harry expresses doubt that Wiggins comes from an industrial district. However, he also indicates that he believes that Wiggins is pro-union. Sharon's intention to get Harry to believe that Wiggins's district is industrial was not achieved. Consequently we may infer that her intention to get him to believe that Wiggins is pro-union also failed. However, Sharon need not try to provide alternate support for either her pro-union or anti-NAFTA claims. This is because Sharon's intention to convince Harry that Wiggins's district is industrial was held in service of the intention to get Harry to believe in Wiggins's pro-union position. That is, there was a causal connection between the industrial-district intention and the pro-union intention; because Harry's response explicitly indicates that the pro-union intention was achieved, the outcome of those intentions which served as preconditions to it or as effects in subplans of it can be ignored.[2]

Responses H4 and H5 are variations of H1 through H3. Their analysis is left to the reader.

[2]If, on the other hand, it is important to Sharon (for some other reason) that Harry also believe that Wiggins comes from an industrial district, then she may need to reconvince him of this.

As can be seen in these examples, a wide range of responses to Harry's replies are possible. Each of Harry's replies provides feedback about the outcome of a small subset of Sharon's intentions. In order to respond appropriately, Sharon must be able to determine what implications this feedback has on the ultimate success of her other intentions.

A Discourse Plan for Our Example

We now describe how the DPOCL system represents Sharon's utterance under the analysis given above; see Figure 3.

The manner in which a hearer combines the information in an utterance with his prior beliefs is critical to the generation of the utterance. Most previous work has made use of highly simple models of this process: for instance, it has assumed that the effect of asserting a proposition p is either that the hearer believes or does not believe p. In fact, a speaker may go to great lengths to convince the hearer of the truth of a proposition. She may first assert it, then support it, and then provide support for the intermediate statement. In such a case, the speaker presumably believes that the combination of utterances is what leads the hearer to accept the main proposition. A complete model of this phenomenon is beyond the scope of this paper; we hint at it by representing the combination of multiple partial beliefs with the action Combine-Belief($\vec{x}$), where $\vec{x}$ is a vector of relevant beliefs. The strength of belief L that a hearer has in a particular proposition P is represented informally by the formula Bel(P, L).

In Figure 3 we abbreviate propositions as follows: N represents Wiggins will vote No on NAFTA, U represents Wiggins is pro-union and I represents Wiggins comes from an industrial district. Those conditions surrounded by boxes are true in the initial state – causal link arcs connecting them to the initial state are omitted for clarity.

The DPOCL data structure for representing plans consists of five components:

- **Steps:** Each discourse action in the plan is represented by a step. These steps are the nodes in the plan graph. Steps are instantiated from action operators representing the action's preconditions and effects. Steps may be composite, representing abstract actions like Cause-to-Believe(U), or primitive, representing those actions that are directly executable by the system, such as Inform(I).

- **Decomposition Links:** Decomposition links connect a parent step to the initial and final steps of the subplan that achieves the parent step's effects. The decomposition links are shown using dashed arcs; they capture the hierarchical structure of the plan.

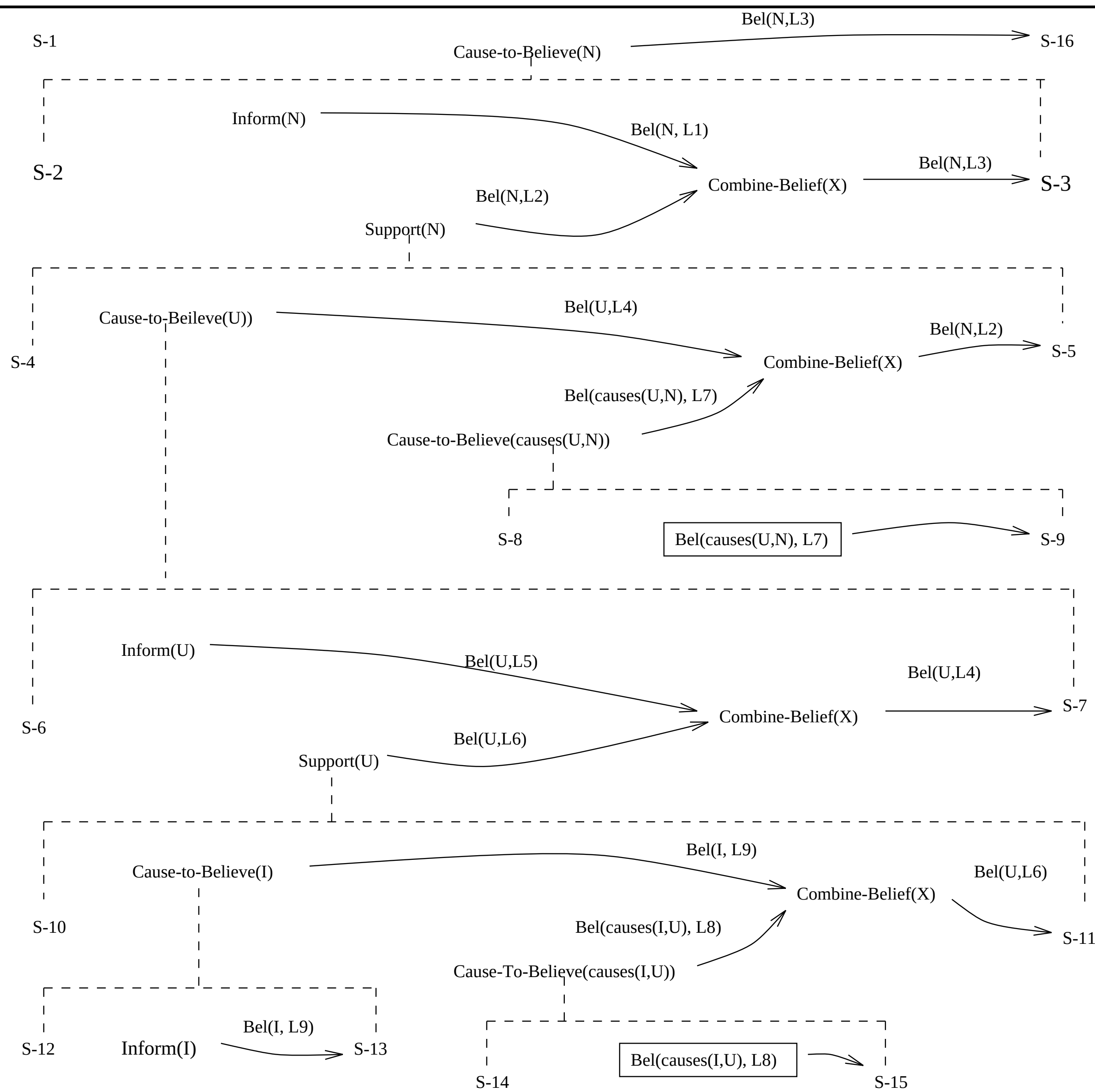

Figure 3: An Example Discourse Plan

- **Causal Links:** Causal links connect two steps when the first step establishes a precondition for the second step. They are shown using solid arcs and are labeled with the effects that they contribute.
- **Ordering Constraints:** The set of ordering constraints defines a partial temporal ordering over the steps in the plan. For readability, these constraints are not shown in Figure 3.
- **Binding Constraints:** The set of binding constraints provide codesignation relationships for variables occurring in the steps of the plan. For readability, all variables in the plan shown in Figure 3 have been replaced by object constants specified by the plan's binding constraints.

DPOCL uses the standard technique of encoding the initial conditions and the goals of a planning problem as the effects of a null initial action and the preconditions of a null final action, respectively. Similarly, in an action decomposition, there is a null initial action that has as its effects exactly the preconditions of its parent action, and a null final action that has as its preconditions the effects of its parent. The DPOCL planner attempts to achieve the preconditions of a subplan's final step in the same manner as it achieves all other unsatisfied preconditions. In this way we guarantee that the effects of every composite action are achieved by the steps in its subplan. Furthermore, the exact relationship between the actions in a subplan and the establishment of those effects is made explicit.

By analyzing the causal and decompositional structure of the discourse plan, we can determine an appropriate response for each of Harry's replies discussed above:

- **H1:** In this case, the effect Bel$(I, L9)$ asserted by the Inform(I) was not achieved. From our representation, it is possible to trace a path of failed effects from Inform(I) across causal links and up decompositional links to Cause-To-Believe(I), Support(U) and eventually to Cause-To-Believe(N). Using this information, the system can determine that appropriate responses to H1 can be generated by trying to convince Harry that Wiggins's district is, in fact, industrial (i.e, replanning the subtree rooted at the node Cause-To-Believe(I), most likely by providing support for I), finding some other support for the claim that Wiggins is pro-union (i.e, replanning the subtree rooted at the node Support(U)), or finding some other means to support the anti-NAFTA claim altogether (i.e, replanning the subtree rooted at the node Support(N)).
- **H2:** The DPOCL plan in Figure 3 is predicated on the truth of Bel(causes$(I, U), L8)$, i.e., that this proposition is an effect of the initial step. In H2, Harry reveals that this proposition is false. As in the previous case, an appropriate response results from the re-planning of subtrees whose execution is affected by this failure. Specifically, those subtrees rooted at Cause-To-Believe(causes(I, U)) across causal links and up decompositional links to Support(U) and eventually to Cause-To-Believe(N). Note that this does not include the subtree rooted at Cause-to-Believe(I) and thus, unlike in H1, the system will not attempt to reestablish the proposition that Wiggins's district is industrial.
- **H3:** In this case, the speaker is given more information about the success of the original plan. As in H1, the effect Bel$(I, L9)$ is not achieved. However, here Harry also indicates that the effect Bel$(U, L4)$ of the step Cause-To-Believe(U) *has* been achieved. Cause-To-Believe(U) lies along the only causal path from Inform(I) to the plan's final step. Since it achieved its intended effect, re-planning any of its subplans is unnecessary.

Although this example did not explicitly illustrate how our representation addresses cases where action descriptions have multiple effects, it is clear our model can handle such cases appropriately. Our solution rests on the fact that our model makes a clear distinction between effects of discourse actions that play a role in achieving the top-level goals of the discourse plan and effects that are not important for achieving the agent's ultimate goals (i.e., side effects).

How DPOCL Creates Discourse Plans

So far we have focused on the representation used by DPOCL. We now briefly describe how the DPOCL algorithm works. In DPOCL, the process of creating a completed plan involves iterating through a loop that chooses between refining the current plan decompositionally (expanding a composite action by adding its subactions to the plan) or refining the plan causally (choosing some action's unsatisfied precondition and adding a new action and the causal link establishing it). Figure 4 summarizes the DPOCL planning algorithm. For more details of the algorithm and a discussion of its formal properties, see (Young, Pollack and Moore, 1994).

The representation of each action is separated into two parts corresponding to the causal and decompositional roles the action plays: the action operator, and a possibly empty set of decomposition operators. The action operator captures the action's preconditions and effects. These preconditions and effects are sets of first-order quantified sentences similar to the typical precondition and add/delete lists of STRIPS (Fikes and Nilsson, 1971). Each decomposition operator represents a single-layer expansion of a composite step, essentially providing a partial specification for the subplan that achieves the parent step's effects given its preconditions. In addition to specifying the steps in the subplan, the decomposition operator specifies any variable binding and

temporal ordering constraints between the steps, and the causal links between steps of the subplan that enable them to establish the parent step's effects.

The formal specification of the DPOCL algorithm relies on nondeterministic choice to guide its search through the space of partial plans. Each choice is recorded, and backtracking occurs when appropriate. Nondeterministic choice is specified in order to allow DPOCL implementations to specify domain-dependent search control. As long as search control heuristics guarantee that all possible choices will be explored, the implementation remains complete.

As a result of adding steps to a plan, newly created steps may introduce *threats* to existing causal links. A step A threatens a causal link between two steps B and C when A might occur between B and C and one of A's effects might undo the condition established in the causal link. To ensure that no causal links are undone, each threat is dealt with before planning proceeds, either by ordering the steps so that the threatening step cannot occur between the two causally-linked steps or by restricting the variable bindings of the steps to eliminate harmful interactions. This process is iterative, since each modification to resolve a threat may introduce new ones.

In the example discussed earlier, the DPOCL planner is invoked with the partial plan consisting of the null initial action S-1, whose effects are Bel(causes$(U, N), L7)$ and Bel(causes$(I, U), L8)$, and the null final action S-16, whose only precondition is Bel$(N, L3)$. By iterating through the DPOCL loop shown in Figure 4, the plan shown in Figure 3 is constructed. This plan is completed, that is, the preconditions of all actions have been established by causal links, there are no threats to any of these links, and all composite actions have been decomposed into subplans terminating in executable actions at the leaf nodes.

This plan makes explicit the causal connections between each effect and the precondition that relies upon it. Similarly, the decomposition links make explicit the manner in which actions in a subplan establish the effects of the parent step. This representation makes it possible for a system playing the role of Sharon to respond appropriately to each of Harry's replies as described earlier.

Conclusions

In this paper, we have presented a structure for discourse plans that draws on state-of-the-art AI planning research. Both the plan representation and the discourse planning algorithm that we use to construct it have a well-defined semantics whose formal properties can be analyzed (Young, Pollack and Moore, 1994). Further, we have shown how DPOCL discourse plan structures can be used for determining appropriate responses to utterances that indicate a failure of some part of the discourse plan.

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Termination: If the plan is inconsistent, then backtrack. Otherwise, remove unused step and return the plan.

Plan Refinement: Non-deterministically do one of the following:

1. **Causal Planning:**
   (a) **Goal Selection:** Nondeterministically select a goal.
   (b) **Operator Selection:** Add a step to the plan that adds an effect that can be unified with the goal (either by instantiating the step from the operator library or by finding a step already in the plan). If no such step exists, backtrack. Otherwise, add the binding constraints required for the conditions to unify, an ordering constraint that orders the new step before the goal step and add the causal link between the two.

2. **Decompositional Planning:**
   (a) **Action Selection:** Nondeterministically select some unexpanded composite step in the plan.
   (b) **Decomposition Selection:** Nondeterministically chose an appropriate decomposition schema for this action whose constraints are satisfied. Add the steps and subplan components of the decomposition schema to the plan and update the list of decomposition links to indicate the new subplan.

Threat Resolution: Find any step that might threaten to undo any causal link. For every such step, nondeterministically do one of the following:

- **Promotion** If possible, move the threatened steps to occur before the threat in the plan.

- **Demotion** If possible, move the threatened steps to occur after the threat in the plan.

- **Separation** If possible, add binding constraints on the steps involved so that no conflict can arise.

Recursive Invocation Call the planner recursively with the new plan structure.

Figure 4: The DPOCL Algorithm